The tempo of change in the leeward Kohala field system, Hawai‘i Island

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Abstract

Reanalysis of radiocarbon dates that pre-date features of the leeward Kohala field system on Hawai‘i Island was carried out within a Bayesian statistical framework. Results of the analysis indicate that features of the field system were developed late in traditional Hawaiian times. Many of the features appear to have been constructed subsequent to Cook’s visit in AD 1779. These results do not support the hypothesis that agricultural intensification began in the early seventeenth century, linked to a rise in the authority of chiefs.

Introduction

Archaeology’s radiocarbon revolution has been a blessing and a curse for archaeologists working in Hawai‘i. When the method was first applied in the early 1950s it appeared to offer a scientific way to measure time that would be an improvement over relative dating methods that had yielded poorly in Hawai‘i (Dye 2010). In practice, however, many of the ^{14}C age determinations returned by dating laboratories proved difficult to interpret sensibly. Over the years, archaeologists have responded with a variety of interpretive schemes, all of them ad hoc in the sense that they are not based on an explicit chronological model. Ad hoc interpretive schemes are certainly capable of yielding good results, but the history of their application in Hawai‘i is symptomatic of an unscientific method. This is perhaps easiest to see in the case of Polynesian colonization, a question that has been at the forefront of archaeological research in Hawai‘i since the dawn of the radiocarbon revolution. In science, a properly formulated solution yields increasingly accurate and precise results as the number of relevant observations grows. In contrast, the ad hoc interpretive approaches have disdained precision, proposing colonization date estimates without corresponding error terms, and have failed to converge on a solution (Dye 2011). Ad hoc estimates of the colonization event proposed over the last two decades range over an eye-opening 1,200 years.

This paper argues that the failure of ad hoc interpretive methods is systemic. Statements about what happened in old Hawai‘i based on ad hoc interpretations often reflect failures of the method more than they do events in the past. An example is a general statement about sequences of agricultural development across the archipelago.

> “… the chronological development of the Kohala, Kona, Waimea, Kahikinui, and Kalaupapa field systems, spanning three islands, is remarkably congruent. While there was some low intensity land use in Kohala and Kona prior to AD 1400, in all cases the onset of major dryland cultivation began around AD 1400. Following about two centuries of development, a final phase of intensification, typically marked by highly formalized garden plots and territorial boundaries, commenced about AD 1600 to 1650, and continued until the early post-contact period. Unlike the irrigation systems, many of which have continued in use throughout the nineteenth and twentieth centuries, the dryland field systems were all rapidly abandoned within a few decades following European contact” (Kirch 2010: 153).

This statement is part of a larger argument about the chronology of changes in *ali‘i* authority (Kirch 2010: 77 ff.), which has its basis in interpretations of traditions that were transmitted by the ruling *ali‘i*, and which served to legitimate their rule. The period boundaries for agricultural development define evenly spaced, approximately two-century intervals that link features of the contact-era political situation with origination points identified by interpretation of the traditions. The “onset of major dryland cultivation” in AD 1400 is when some scholars believe the traditions become historically accurate, in the western sense of that term (Kirch 2010: 81). In this interpretation of the traditions, *ali‘i* history begins around AD 1400. The “final phase of intensification” around AD 1600 marks the first Gregorian century in which the traditions are interpreted to indicate that Hawai‘i and Maui Islands were both ruled by paramount chiefs. The Hawai‘i Island *ali‘i*, ‘Umi a Līloa, whose reign was later used to legitimate Kamehameha the Great’s usurpation of the Hawai‘i Island paramountcy on his way to uniting the islands, ruled at about this time. Thus, field system developments are seen as congruent among themselves and also with a particular interpretation of the development of political authority in traditional Hawai‘i.

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It is argued here that congruencies such as these are, in part, artifacts of the ad hoc methods used to interpret the dating evidence. Ad hoc methods spawn two kinds of errors, both of which bolster the appearance of congruence. First, their disdain for uncertainty conceals the fact that age estimates for some key events are very imprecise. In these cases, linking the archaeological record to a precise time doesn't constitute archaeological support for a particular hypothesis. Rather, it reflects an assumption of the hypothesis to shore up weaknesses in the archaeological results. Second, the ad hoc methods operate outside a coherent statistical framework and are typically wasteful of chronological information. They yield relatively weak results. Precise results with the potential to distinguish one chronology from another are thus kept out of reach, leaving the impression of congruence intact.

This general argument is made by way of a specific example, a model-based calibration and re-interpretation of the developmental chronology of a portion of the leeward Kohala field system on Hawai'i Island. The leeward Kohala field system offers a unique opportunity in this regard. As Rosendahl (1972) pointed out many years ago, the fabric-like structure of the field system—trails that connect the field system to the coast provide the warp for the weft of agricultural walls that divide fields from one another—yields an opportunity to establish relative ages of features at every intersection of a wall with a trail. Within this rich mesh of chronologically ordered construction events, Ladefoged and Graves (2008) have carried out a sophisticated dating program that specifically excavated beneath agricultural walls and under curbstones of trails to identify *termini post quem* for wall and curb construction events. The detailed dating record they have produced offers analytic opportunities that are unmatched in Hawaiian archaeology. It is the only dating record from the leeward Kohala field system capable of yielding the analytic precision required to evaluate the proposed temporal congruence.

This rich set of data is analyzed here with Bayesian methods (Buck et al. 1996), which build a detailed chronological model of field system development from the stratigraphic relations of the agricultural walls and trails, and then fix this model in time with the ^{14}C age determinations. The ^{14}C age determinations from the field system are generally quite young and their combination with the detailed chronological model yields results that are more precise than typically achieved in Hawai'i. The precision of the results adds strength to the observation that they are not congruent with the chronology of political development yielded by the interpretation of *ali'i* traditions. Instead of the steady march of change implied by the ad hoc interpretation, the Bayesian analysis indicates that the tempo of change varied over time. Much of what we recognize today as the field system—most of the walls and many of the trails—was built during a brief pulse of intensification at the end of the sequence. In fact, much of the construction appears to have taken place within the historic period, which suggests that contingent events might have played a larger role in agricultural development than the interpretation of *ali'i* traditions would lead one to expect.

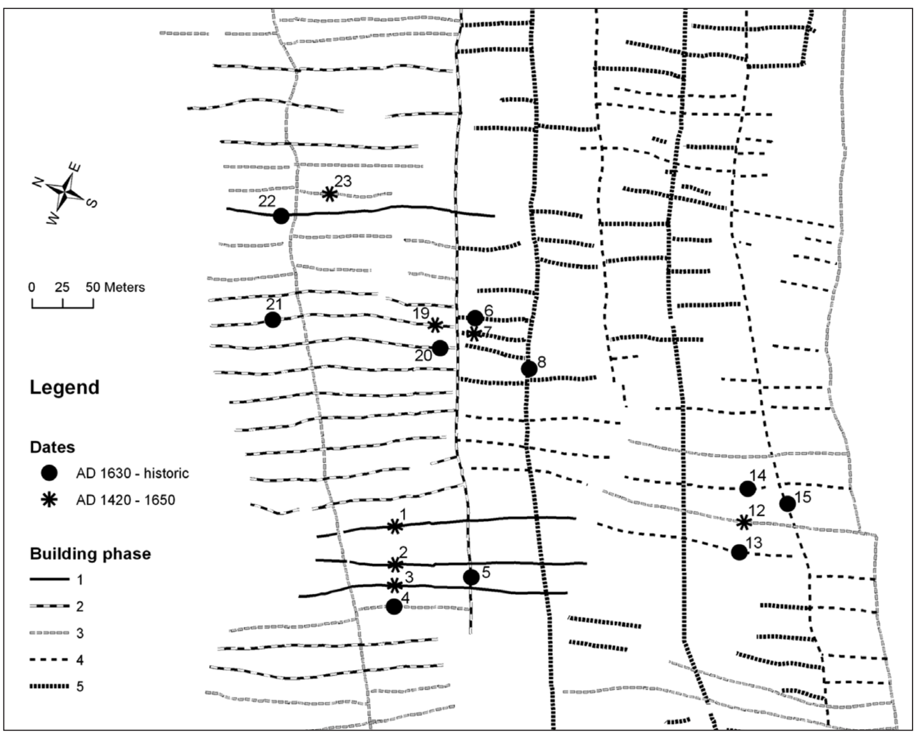

Figure 1. Periodization of field system features by building phase (after Ladefoged and Graves 2008: Figure 7).

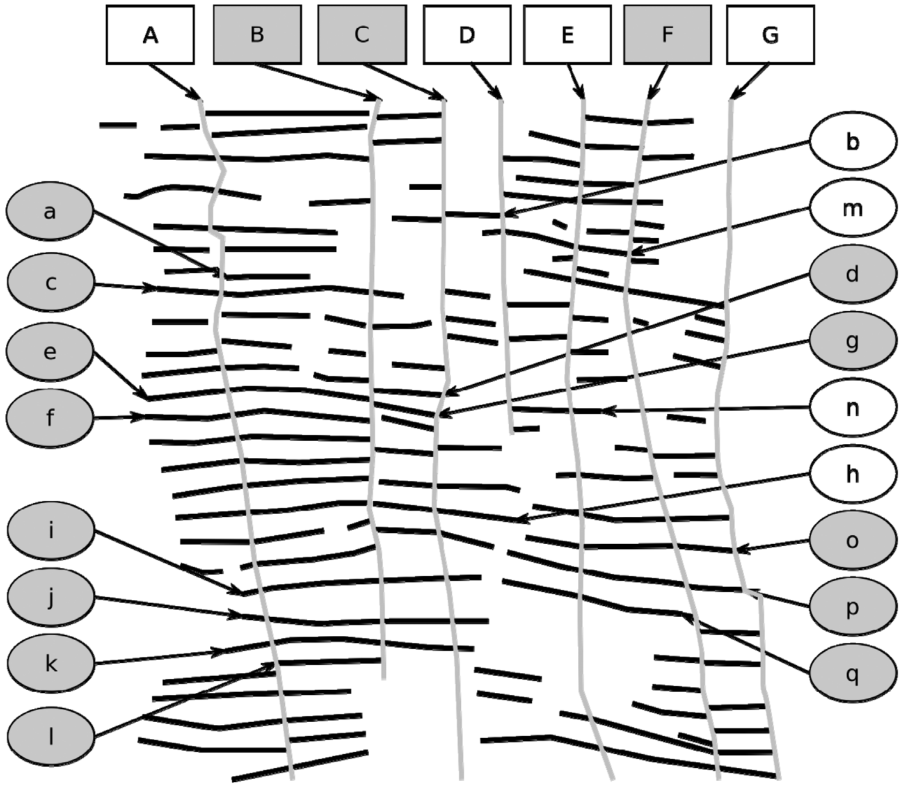

Figure 2. Diagram of the detailed study area. Uphill is toward the top of the diagram. Trails are indicated by capital letters in boxes and walls by lower case letters in ovals. The labels of dated features are shaded gray.

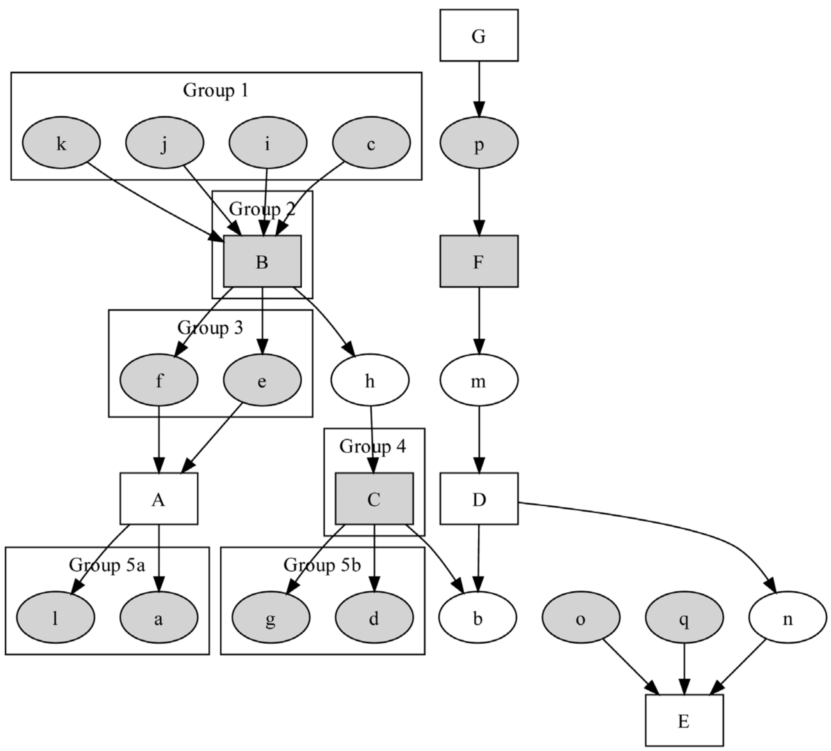

Figure 3. Chronological model of field system features. Features are labeled as in Figure 2.

Relative Chronology of Field System Development

The relative chronology of field system development in the detailed study area has been addressed in two publications (Figure 1) (Ladefoged et al. 2003; Ladefoged & Graves 2008). In these cases, the field system features were assigned to building phases or temporal units; two similar analytic constructs that group features based on stratigraphic relations and a set of propositions or assumptions independent of the stratigraphic relations. The chronological model used in the Bayesian calibration is based solely on stratigraphic relations, so it can't be based on the published building phases or temporal units (Figure 2).

Accordingly, a Harris matrix (Harris 1989) of the dated field system features was constructed (Figure 3). In addition to the dated field system features, also included in the Harris matrix are undated features that show the relative stratigraphic relations of dated features that don't intersect one another, but whose relationship can be determined with the map evidence. Figure 3 thus represents the components of the full Harris matrix for the detailed study area needed to construct a chronological model for the Bayesian calibration. This figure represents the chronological model that distinguishes Bayesian from ad hoc interpretations.

Figure 3 is a directed acyclic graph, also known in the literature as a DAG or an acyclic digraph. The properties of DAGs are well known and graph theory has developed terminology that makes it possible to talk about them in a precise way (Hage & Harary 1983: 65 ff.). This can be a tremendous advantage when trying to conceptualize and work with a structure as large and complex as the detailed study area (Figure 2). It would appear to be essential to any attempt to deal with larger sections of the field system or to comprehend the field system whole.

The properties of a DAG make it an ideal graph structure to represent a Harris matrix. A DAG consists of a finite set of *points* and a collection of ordered pairs of points, known as *arcs* (Hage & Harary 1983: 68). The *directed* property of the DAG refers to the fact that each arc consists of an ordered pair of points, or a direction that runs from the first point to the second point. In the context of a Harris matrix, the direction of an arc encodes the stratigraphic relation "older than/younger than." In Figure 3, the arrows used for the arcs of the graph point from an older feature to a younger feature; each arrow represents an observed stratigraphic relationship at the intersection of a trail and a wall. The *acyclic* property of the DAG means that there is no sequence of points and arcs, where the points of each arc are in order, that starts and ends at the same point. The lack of cycles in the graph ensures that no feature can be either older or younger than itself, which is a requirement of the stratigraphic model.

Figure 3 is laid out with the arrows pointing down, so older features are at the top of the graph and younger features are at the bottom. The structure of the graph, with alternating rows of walls and trails, reflects the nature of the evidence; none of the walls cross another wall, and none of the trails cross another trail. Two features are related chronologically if and only if one is *reachable* from the other; two points in a digraph are reachable if it is possible to move from one to the other in the direction of the arcs. Walls *g* and *d*, for instance, are reachable from the same set of features, which includes walls *c*, *i*, *j*, *k*, and *h* and trails *B* and *C*. They are not, however, reachable from one another. Thus, although the stratigraphic relations indicate that both walls are younger than trail *C*, it is not possible to tell on the basis of the relative stratigraphic information which of the two was built before the other.

The graph of Figure 3 is *weakly connected* because it contains pairs of points that are not reachable from one another. This occurs fairly frequently in situations like the one discussed above with walls *d* and *g*, where the walls are physically close to one another and share similar stratigraphic relations to neighboring trails. It also occurs frequently with walls on opposite sides of a trail. For example, walls *d* and *e* are both younger than trail *B*, but it is not possible to determine on stratigraphic grounds which of the walls is older than the other. It is true that wall *e* is older than trail *A* and that wall *d* is younger than trail *C*, but there is no stratigraphic information on the relative ages of trails *A* and *C*, so this information does not yield a temporal order for the two walls. The fact that the periodization of Figure 1 assigns relative ages to these two walls, and to others that share similar stratigraphic relations, is an indication that the building phases it proposes are not strictly chronological.

These two examples of weak connections are both local in scope. However, weak connections also occur at points that distinguish larger sections of the field system, and these might provide clues to the history of development. The prime example of this in the detailed study area is wall *b*. None of the points that reach wall *b* from the left hand side of Figure 3 is reachable from any of the points that reach wall *b* from the right hand side of the figure. Thus, the stratigraphic structure of the detailed study area is broken between trails *C* and *D* in Kahua 1.

^{14}C Dating of Field System Features

Table 1 lists 21 of the 25 ^{14}C age determinations associated with agricultural features in the leeward Kohala field system published by Ladefoged and Graves (2008: Table 1). It includes all 17 ^{14}C age determinations from the detailed study area at Pāhinahina and Kahua 1, along with four of the eight ^{14}C age determinations from features outside the detailed study area. All of the age determinations in the table are on short-lived materials. The four excluded ^{14}C age determinations are on materials identified as dicot wood. They were excluded because of the potential in-built age carried by this material. The ^{14}C age determinations all derive from archaeological contexts that "date activities that occurred before the construction of the agricultural walls"

θ*	Feature†	Group‡	Beta-	CRA§	Outlier	KRC-
8	i	1	189729	290 ± 40	-2%	1
9	j	1	189730	440 ± 40	6%	2
10	k	1	189731	420 ± 40	2%	3
11	c	1	208141	200 ± 40	20%	22
12	e	3	208138	320 ± 40	5%	19
13	f	3	208139	160 ± 40	-3%	20
14	e	3	208140	150 ± 40	-3%	21
15	l	5a	189732	210 ± 40	1%	4
16	a	5a	208142	340 ± 40	-3%	23
17	d	5b	189734	250 ± 40	3%	6
18	g	5b	189735	410 ± 40	3%	7
19	p	garden	189740	330 ± 40	n/a	12
20	q	garden	189741	150 ± 30	n/a	13
21	o	garden	189742	130 ± 30	n/a	14
22	B	2	189733	130 ± 30	-1%	5
23	C	4	189736	140 ± 30	-3%	8
24	F	garden	189743	210 ± 40	n/a	15
25	T-12	garden	189737	470 ± 40	n/a	9
26	T-21	garden	189745	460 ± 40	n/a	17
27	T-22	garden	206590	280 ± 40	n/a	18
28	T-50	garden	208143	580 ± 40	n/a	24

Table 1. ^{14}C age determinations.
* See http://www.tsdye.com/research/tempo.html.
† See Figure 2.
‡ See Figure 1 and http://www.tsdye.com/research/tempo.html.
§ Conventional ^{14}C age (Stuiver & Polach 1977).
Source: Ladefoged & Graves (2008).

or that “pre-date the construction of the trails” (Ladefoged & Graves 2008: 778).

Table 1 provides the label assigned to the age determination by Ladefoged and Graves (2008) in the last column; the label assigned by the dating laboratory in column 4; the wall or trail feature with which the age determination is associated, keyed to Figure 2, in column 2; and the calibration group to which the determination has been assigned in column 3. The values in the first column, labeled θ, identify the age determinations in the Bayesian analysis. Technically, in the Bayesian model each θ represents the true calendar age of the sample, which is estimated by the corresponding ^{14}C age determination. The values in the table start with θ_8 and run through θ_{28}. This is because the field system calibration is carried out in the context of an estimate of when the islands were initially colonized by Polynesians, which requires seven age determinations assigned to $\theta_{1...7}$ (Dye 2011). The column labeled “Outlier” is an analytic result, discussed below.

A striking feature of Table 1 is that most of the ^{14}C age determinations are relatively young. This is the case even for ^{14}C age determinations associated with the oldest features in the detailed study area. Two of the ^{14}C age determinations associated with Group 1 walls are less than 300 ^{14}C years old, and the youngest of these, associated with wall *c*, dates to 200 ± 40 BP. The sample collected from beneath the curbstone of the oldest trail, trail *B*, dates to 130 ± 30 BP. Keeping in mind that these ^{14}C age determinations pre-date construction of the associated features, and that the field system was abandoned “within a few decades following European contact” (Kirch 2010: 153), or about 100 BP, it would appear that most of the features in the detailed study area were built within the span of about 100 ^{14}C years.

Because a 100 ^{14}C year span seems too brief for construction of the field system facilities, an analysis was performed to identify outliers among the ^{14}C age determinations (Christen 1994). The expectation was that the young age determinations associated with the oldest features would be identified as outliers and could be removed from the calibration. The results of the outlier analysis are presented in column 6 of Table 1 as the difference between an uninformative prior probability assigned to each ^{14}C age determination and the posterior probability returned by the analysis. Negative numbers indicate ^{14}C age determinations that are less likely to be outliers than was estimated by the prior probability and positive numbers indicate ^{14}C age determinations that are more likely to be outliers. The outlier identification procedure doesn't establish a metric for how big this difference must be for a ^{14}C age determination to be considered an outlier. In practice, the analyst uses the results to draw attention to particular ^{14}C age determinations and these are scrutinized as necessary before a decision is made either to keep them in the analysis or discard them as outliers.

The results of the outlier analysis indicate that there is no reason to question the integrity of most of the age determinations. The young age determination from under the curbstone of trail *B* and the age determination associated with wall *i* in Group 1 are not outliers. The only age determination possibly indicated by the analysis as an outlier is the age determination associated with wall *c*. Ladefoged and Graves (2008: 779) don't discuss this particular age determination and it appears not to have played a role in their interpretation of the dating results. However, there are several reasons why this age determination should not be treated as an outlier: (i) the dating model typically has few age determinations per group and this makes outlier determination less reliable than it would be with more samples; (ii) the result returned by the outlier analysis is not particularly strong—the prior probability of 0.1 increased to 0.3, about a quarter of the possible maximum; (iii) the ^{14}C age determination is only 90 ^{14}C years younger than the next youngest sample from beneath a Group 1 wall; (iv) the ^{14}C age determination associated with the feature immediately younger than it, trail *B*, is stratigraphically correct and about 70 ^{14}C years younger than it; and (v) charcoal from the later swidden activities might be relatively rare if, as appears to be the case, secondary growth were consistently used as a source of mulch, or if burned secondary growth consisted mostly of grasses (Kirch 2010: 53). On balance, then, there appears to be no compelling reason to discard this age determination as an outlier. However, this is an issue that might repay identification and dating of additional samples from beneath Group 1 walls.

Developmental Periods and Their Boundaries

The history of the leeward Kohala field system is typically described according to a theory of agricultural development that distinguishes processes of expansion and intensification (Kirch 2010; Ladefoged & Graves 2008, 2010). The process of expansion involves "conversion of previously unused areas to cultivation" (Ladefoged & Graves 2010: 95). It is recognized archaeologically beneath the oldest field system walls in units of stratification that "show clear signs of clearing or cultivation, such as digging stick holes, churned sediments, and charcoal lenses or flecking" (Ladefoged & Graves 2008: 778). The process of intensification increases "the amount of labor in a fixed area of land to increase production" (Ladefoged & Graves 2010: 95). It is recognized archaeologically by construction of the field system walls. In use, the walls were typically planted with sugar cane that helped them serve as windbreaks, which increased yields by protecting crops from the famous Kohala winds and reducing evapotranspiration (Ladefoged & Graves 2010: 94).

The periods of expansion and intensification can be augmented with two additional periods that set the leeward Kohala field system within the framework of a first-order cultural sequence for Hawai‘i. The first of these embraces the time between Polynesian colonization and the onset of agricultural expansion. The land that would later become the leeward Kohala field system lay undeveloped and was either unused or used so lightly that archaeologists are unable to detect it. At the other end of the sequence is the time since the field system was abandoned in the mid-nineteenth century. Historically, use of the area during this period was for cattle ranching, but other commercial activities have been attempted, all of them made possible by the introduction of certain property rights and the alienability of land during the *Māhele* (Banner 2005; Chinen 1958, 2002; Moffat & Fitzpatrick 1995). For ease of reference, the periods are here labeled Colonization, Expansion, Intensification, and Alienation. The model was calibrated with the BCal software package (Buck et al. 1999).

Estimates of the period boundaries yielded by the Bayesian calibration are shown in Figure 4. The colonization event is based on model (3) of Dye (2011), which includes a ^{14}C age determination on rat bone from the ‘Ewa Plain that did not control for the possibility of a marine component in the rat's diet that would make the bone appear too old. Model (3) was used because it yields a relatively precise estimate of the colonization event, but one which maintains the central tendency of the less precise estimate without the rat bone date (Dye 2011). Still, the 67% highest posterior density (HPD) region of the estimate, analogous to the one standard deviation error term of frequentist statistics, covers almost two centuries. The 95% HPD region, analogous to two standard deviations, spans more than three centuries. The distribution is centered around AD 980 and is relatively symmetrical.

The estimate for the beginning of the Expansion period is slightly more precise than the estimate of the Colonization period. The 67% HPD covers about 120 years and the 95% HPD about 280 years. The central tendency of the distribution is clearly within the fourteenth century; probabilities drop off quickly after AD 1400, and the long, low early tail takes in the eleventh through thirteenth centuries.

The precision of the estimate improves markedly in the Intensification period, due primarily to the constraints

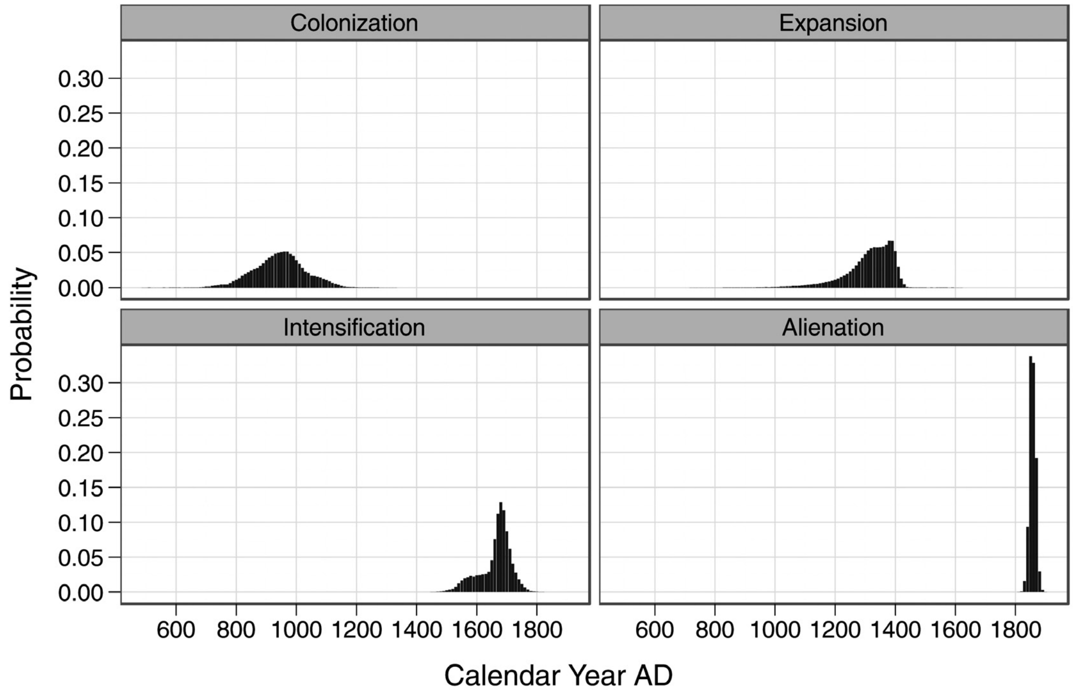

Figure 4. Period boundary estimates. The 67% highest posterior density regions are: *top left*, AD 860–1029; *top right*, AD 1290–1409; *bottom left*, AD 1640–1729; *bottom right*, AD 1850–1869.

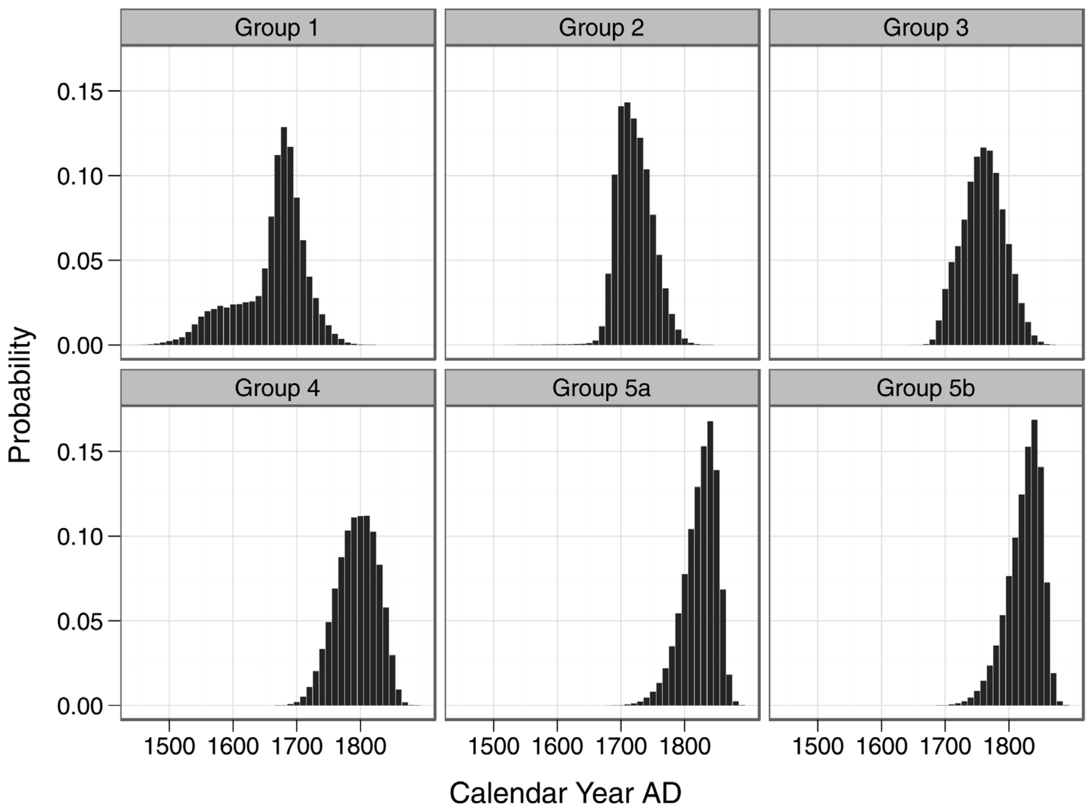

Figure 5. Chronology of dated features in the leeward Kohala field system detailed study area. See Table 2 for estimates of precision and Figure 3 for the definition of groups.

imposed by chronological relations of the field system features (Figure 3). Given the model and current evidence, the 67% HPD covers 90 years and the 95% HPD covers 210 years. The distribution has a marked peak around AD 1680 that falls rapidly in the eighteenth century but has a long, low early tail that extends through the sixteenth century.

The estimate for the Alienation period is included on Figure 6 for the sake of completeness. This period boundary is a floating parameter in the model that was modeled as a normal curve with a ten year standard deviation centered at AD 1850. Land records from the *Māhele* appear to indicate that the field system was abandoned by the middle of the nineteenth century. In any event, archaeological excavations in the field system did not yield information on the abandonment event, so the estimate yielded by the Bayesian calibration is mainly a reflection of the prior probability.

Estimates for the construction of facilities within the detailed study area are shown in Figure 4 and the precisions of the estimates are listed in Table 2. The high precision of these estimates is due to the many constraints yielded by the stratigraphic relations of the trails and walls (Figure 3) and to the apparent brevity of the Intensification period. The estimate for Group 1 is also the estimate for the onset of Intensification and was discussed earlier. Group 2 dates the construction of the curb along trail *B*, which marks the boundary between Pāhinahina and Kahua 1. This trail appears to have been built early in the eighteenth century. The distribution of the estimate is centered on AD 1720, with a 67% HPD region that spans 60 years. The Pāhinahina agricultural walls *e* and *f*, in Group 3, are estimated to have been constructed around the middle of the eighteenth century. The distribution of the estimate is centered on AD 1760. The 67% HPD region spans 70 years. Trail *C*, in Kahua 1, but structurally associated with features in Pāhinahina , appears to have been built around the turn of the nineteenth century. The 67% HPD region for this event spans 60 years. Finally, the two Pāhinahina walls in Group 5a and the two Kahua 1 walls in Group 5b are estimated to be penecontemporaneous. The estimates for these two groups both peak around AD 1840 and both have 67% HPD regions that span 50 years.

Group	67% HPD (AD)	95% HPD (AD)
2	1690–1749	1680–1779
3	1730–1799	1700–1819
4	1770–1829	1730–1859
5A	1810–1859	1770–1879
5B	1810–1859	1770–1869

Table 2. Precision of estimates for facility construction.

Tempo of Change

An alternative view of the calibration results takes the focus away from estimates of period boundaries and puts it instead on estimates of period duration. Figure 6 shows duration estimates for the Colonization, Expansion, Intensification, and Alienation periods.

The Colonization and Expansion periods are both relatively long, on the order of three to five centuries, and imprecisely estimated, with 67% HPD regions between 160 and 260 years. In contrast, the Intensification and Alienation periods are relatively short. Most of the difference in their durations is due to a convention of ^{14}C dating that defines Present as AD 1950. Adding an extra 60 years to the length of the Alienation period would shift its distribution to the right and bring it almost precisely in line with the Intensification period. Duration estimates for both periods are relatively precise, although, as noted above, uncertainty in the duration of the Alienation period is mostly an artifact of the model’s assumptions.

Discussion

The extended quote in the introduction of this paper (Kirch 2010: 153) is structured as an origin narrative. Like other origin narratives, it has two goals—to establish the plausibility of the events and processes it projects onto the past, and to claim authority by locating them at particular times (Moore 1995). This particular origin narrative identifies the processes of agricultural expansion and intensification and fixes their origins at AD 1400 and 1600-1650, two times that an interpretation of tradition finds important in the rise of *ali‘i* authority. The regularity of the process identified in the narrative—200 years of expansion followed by 200 years of intensification into the early historic period—gives it an aura of inevitability, as if the present were predicted by the origin events in its past. Bayesian calibration yields the precise dating results with which to evaluate these claims about agricultural development, at least in a portion of the leeward Kohala field system.

The expansion process, whose origin is described as “the onset of major dryland cultivation” is hypothesized to have originated about AD 1400. This is a time when land was cleared for cultivation of sweet potato, a crop plant that originated in America and was introduced to Eastern Polynesia by voyagers who made the return trip to the coast of South America (Storey et al. 2007). On present evidence, it was introduced to Hawai‘i some three to six centuries after the islands were colonized (Dye 2011: Table 2). Excavations in the leeward Kohala field system collected a charred tuber tentatively identified as sweet potato that represents the earliest dated occurrence of the plant in Hawai‘i (Ladefoged et al. 2005). The ^{14}C age determination for this probable sweet potato tuber, Beta-208143, is the oldest from the field system (Table 1), and thus marks the onset of the Expansion

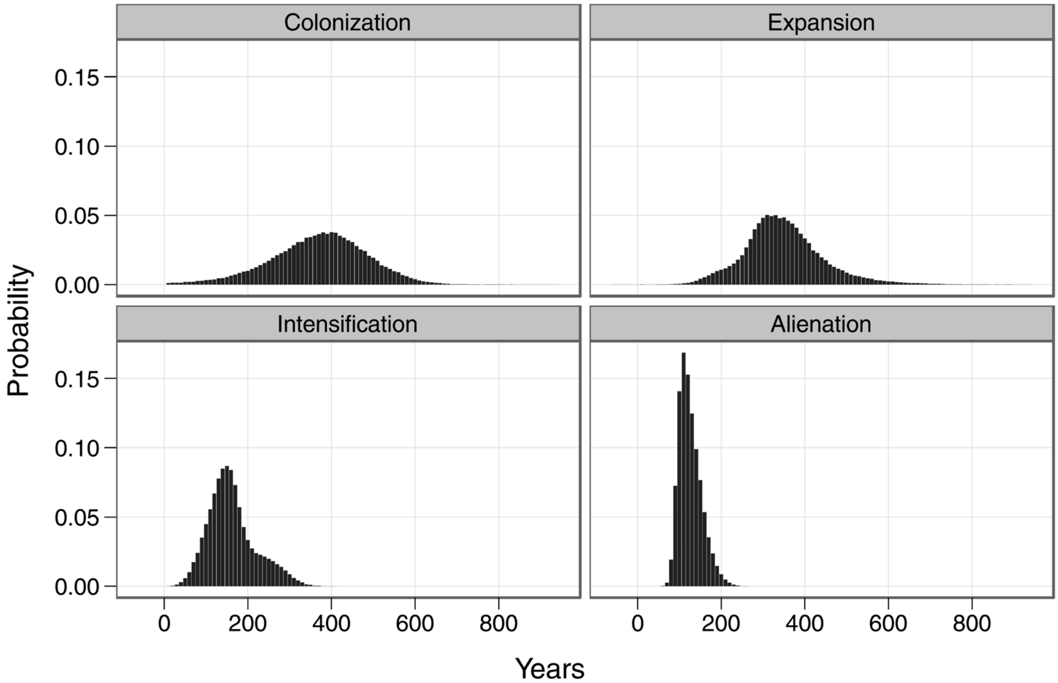

Figure 6. Tempo of change in the leeward Kohala field system. The figure is in row major order with the oldest period in the upper left. The 67% HPD intervals are: *top left*, 270–489 years; *top right*, 260–419 years; *bottom left*, 100–189 years; *bottom right*, 100–139 years. Note that the Alienation period is compressed somewhat by the use of AD 1950 as Present, a convention in ^{14}C dating.

period. Ladefoged and Graves (2008: 779) interpreted this information as placing the start of the Expansion period "as early as AD 1290 but certainly by AD 1430." The Bayesian calibration relies on the same evidence for its estimate and gives a similar result; stratigraphic relations that might constrain the calibrated age of this sample are absent. The date of AD 1400 for the expansion process singled out by the origin narrative falls at the late end of this range. It is a plausible estimate for the onset of the Expansion period, but it is only one of very many plausible estimates. The calibration results from the detailed study area are equally "congruent" with an origin of the Expansion period anytime in the fourteenth century or even a bit earlier. The archaeological information is less certain than the origin narrative implies. In this case, the origin narrative is imposing its structure on the archaeological data rather than the other way around.

The second process identified in the origin narrative is "a final phase of intensification" that "commenced about AD 1600 to 1650." This range of dates is at odds with the interpretation put forward by Ladefoged and Graves (2010), who believed the intensification started earlier. They assign early construction dates to walls *j* and *k* in Group 1 based on the presence of relatively old charcoal beneath them. In their view, this puts the start of the Intensification period "as early as AD 1410 but possibly not until AD 1630" (Ladefoged & Graves 2010: 779). This inference appears to be based on a logical error, however. It is only possible to know that the charcoal collected under a wall is older than the wall; it is not possible to know, in the absence of other information, how much older it is. The Bayesian calibration corrects this logical error and yields a much later estimate. According to it, the intensification process got underway in AD 1640–1729, about a half century later than the range hypothesized by the origin narrative. This disparity grows when the pace of intensification is considered. At least three analyses have indicated that most of the wall construction effort in the leeward Kohala field system was concentrated in the later phases of wall building (Ladefoged & Graves 2000, 2008; Ladefoged et al. 2003). This trend can be seen clearly in the detailed study area in the walls related stratigraphically to trail *B*. There are 28 of these; four belong to the early Group 1 walls and the rest belong to Group 3, which dates to AD 1730–1799, and Group 5, which dates to the early nineteenth century. Thus, the Bayesian calibration indicates that the main thrust of field system intensification can be dated to the eighteenth and early nineteenth centuries. Much of it seems to be a post-contact phenomenon.

This disparity between the hypothesized rise of *ali'i* authority, as intrepreted from *ali'i* traditions, and field system intensification is supported by evidence for development of the spatial structure of the field system. Application of graph theoretic principles to the detailed study area indicates a structural break between trails *C* and *D* within Kahua 1 and not at the boundary of Pāhinahina and Kahua 1 as implied by an earlier analysis (Figure 1). This structural break was not closed until sometime after the curb for trail *C* was constructed, which the Bayesian calibration estimates at AD 1770–1829.

The implication of this finding is that construction projects were carried out in sub-regions of the field system whose boundaries were not coincident with *ahupua‘a* boundaries until relatively late in traditional Hawaiian times and quite possibly into the post-contact era. To the extent that *ali‘i* authority was projected into the field system within *ahupua‘a* land units, this result suggests that *ali‘i* authority played a late, largely post-contact, role in construction of the field system.

A consideration of the tempo of change indicated by the Bayesian calibration contraindicates the impression of regularity and inevitability left by the chronology of the origin narrative. Instead, the expansion of agriculture into the region made possible by the late introduction of sweet potato was a fairly long, drawn out affair that is imprecisely dated with current evidence. This is a period during which expert agriculturalists experimented with a new crop plant in areas that had previously seen little, if any, use. Presumably, it was at this time that the limits of rain-fed cultivation of sweet potato were discovered—the arid boundary of the lowland fields and the nutrient deficient boundary in the wet uplands (Vitousek et al. 2004). Some experimentation with agricultural walls in the late seventeenth century indicate efforts, presumably successful, to control soil moisture against the combined effects of strong winds and variability in precipitation. This long period of expansion and initial experimentation was punctuated, probably early in the historic period, by a period of intensive wall construction and field subdivision that ended less than a century later when the field system was abandoned. The irregular tempo of change revealed by the Bayesian calibration, with a late burst of investment in the field system infrastructure followed soon after by its abandonment, suggests the importance of contingency in the history of agricultural development and raises the possibility that the response to contingent events, which disrupted several hundred years of apparently successful agricultural and social development, was not in the end sustainable.

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References

Banner, S. 2005. Preparing to be colonized: land tenure and legal strategy in nineteenth-century Hawaii. *Law & Society Review* 39(2): 273-314.

Buck, C.E., W.G. Cavanagh & C.D. Litton. 1996. *Bayesian approach to interpreting archaeological data*. Statistics in practice. Chichester: John Wiley & Sons.

Buck, C.E., J.A. Christen & G. James. 1999. *BCal: an on-line Bayesian radiocarbon calibration tool*. http://bcal.sheffield.ac.uk

Chinen, J.J. 1958. *The Great Mahele: Hawaii's land division of 1848*. Honolulu: University Press of Hawai‘i.

——2002. *They cried for help: the Hawaiian land revolution of the 1840s and 1850s*. Honolulu: Jon J. Chinen/Xlibris.

Christen, J.A. 1994. Summarizing a set of radiocarbon determinations: a robust approach. *Applied Statistics* 43(3): 489-503.

Dye, T.S. 2010. Traditional Hawaiian surface architecture: absolute and relative dating. In *Research designs for Hawaiian archaeology: agriculture, architecture, methodology*. Special Publication 3. T.S. Dye (ed.): 93-155. Honolulu: Society for Hawaiian Archaeology.

——2011. A model-based age estimate for Polynesian colonization of Hawai‘i. *Archaeology in Oceania* 46(3): 130-138.

Hage, P. & F. Harary. 1983. *Structural models in anthropology*. Cambridge: Cambridge University Press.

Harris, E.C. 1989. *Principles of archaeological stratigraphy*. Second Edition. London: Academic Press.

Kirch, P.V. 2010. *How chiefs became kings: divine kingship and the rise of archaic states in ancient Hawai‘i*. Berkeley: University of California Press.

Ladefoged, T.N. & M.W. Graves. 2000. Evolutionary theory and the historical development of dry-land agriculture in North Kohala, Hawai‘i. *American Antiquity* 65(3): 423-448.

——2008. Variable development of dryland agriculture in Hawai‘i: A fine-grained chronology from the Kohala field system, Hawai‘i Island. *Current Anthropology* 49(5): 771-802.

——2010. The leeward Kohala field system. In *Roots of conflict: soils, agriculture, and sociopolitical complexity in ancient Hawai‘i*. School for Advanced Research Advanced Seminar Series. P.V. Kirch (ed.): 89-110. Santa Fe: SAR Press.

Ladefoged, T.N., M.W. Graves & M. McCoy. 2003. Archaeological evidence for agricultural development in Kohala, island of Hawaii. *Journal of Archaeological Science* 30: 923-940.

Ladefoged, T.N., M.W. Graves & J.H. Coil. 2005. The introduction of sweet potato in Polynesia: early remains in Hawai‘i. *Journal of the Polynesian Society* 114: 359-373.

Moffat, R.M. & G.L. Fitzpatrick. 1995. *Surveying the Mahele: mapping the Hawaiian land revolution*. Volume 2. Palapala‘āina. Honolulu: Editions Limited.

Moore, H. 1995. The problems of origins: poststructuralism and beyond. In *Interpreting archaeology: finding meaning in the past*. I. Hodder, M. Shanks, A. Alexandri, V. Buchli, J Carman, J. Last and G. Lucas (eds.): 51-53. London: Routledge.

Rosendahl, P.H. 1972. Aboriginal agriculture and residence patterns in upland Lapakahi, island of Hawaii. Unpublished PhD Dissertation. University of Hawai‘i.

Storey, A.A., J.M. Ramirez, D. Quiroz, D.V. Burley, D.J. Addison, R. Walter, A.J. Anderson, T.L. Hunt, J.S. Athens, L. Huynen & E.A. Matisoo-Smith. 2007. Radiocarbon and DNA evidence for a pre-Columbian introduction of Polynesian chickens to Chile. *Proceedings of the National Academy of Sciences* 104(25): 10335-10339.

Stuiver, M. & H.A. Polach. 1977. Discussion: reporting of ^{14}C data. *Radiocarbon* 19: 355-363.

Vitousek, P.M., T.N. Ladefoged, P.V. Kirch, A.S. Hartshorn, M.W. Graves, S.C. Hotchkiss, S. Taljapurkar & O.A. Chadwick. 2004. Soils, agriculture, and society in precontact Hawai‘i. *Science* 304: 1665-1669.

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